Fermilab

Electrical Engineering Department --MS#222
Wilson Hall 14th Floor

To: File

From: Craig Drennan

CC:

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Re: Readout Electronics for the MiniBoone Target BPM’s

1. Introduction

We have developed new readout electronics for Beam Position Monitors to be used for the MiniBoone experiment. The readouts will only be used on the four BPM's nearest the target. The scheme is to demodulate the RF signals from each channel of a BPM using a synchronous demodulation scheme and then digitize the demodulated signals using the 10 MSPS "Quicker Digitizer" available in the IRM, Internet Rack Monitor networked DAQ chassis.

This note describes the BPM RF signal demodulation and the electronics available for online testing of the readout electronics.

2. The BPM RF Signal

The beam we are trying to measure consists of 84 proton bunches arriving at a 53 MHz rate. The signal from the plates of the BPM appears as approximately 100 MHz sine waves occurring at a 53 MHz rate, that is at an interval of 18.9 ns. The typical signal is illustrated in Figure 2.1 and its frequency spectrum in Figure 2.2.

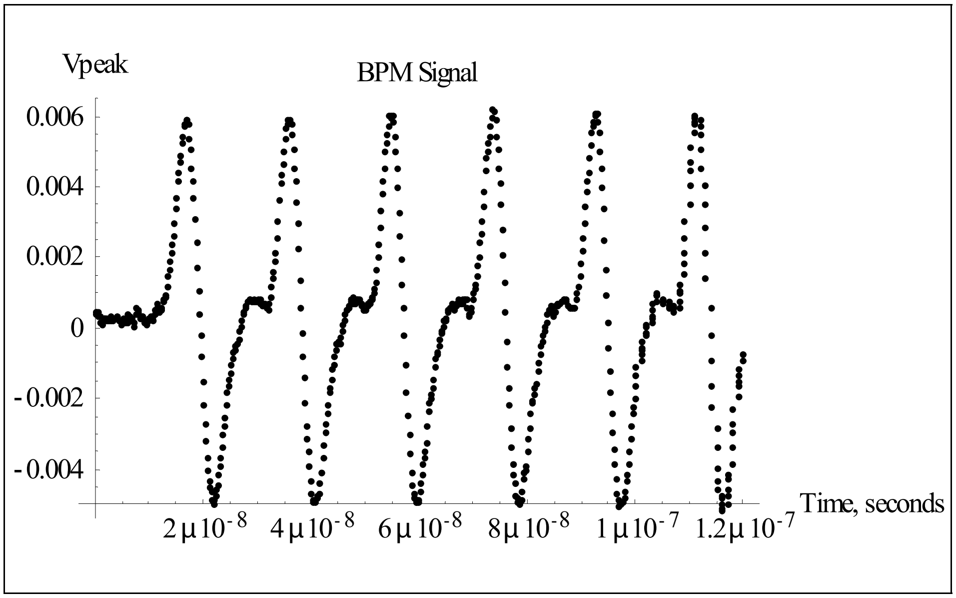

Figure 2.1 BPM signal.

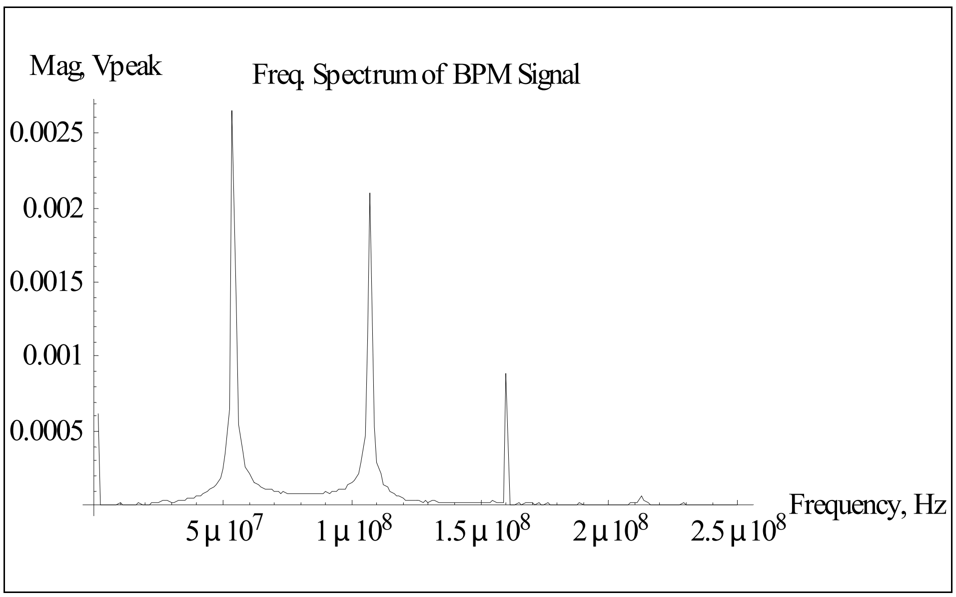

Figure 2.2 The BPM frequency spectrum.

3. The Synchronous Demodulator

The synchronous demodulator extracts the envelopes of the RF signals developed on the plates of the BPM by mixing the signals with a fixed amplitude copy of themselves. The block diagram of the circuit is given in Figure 3.1.

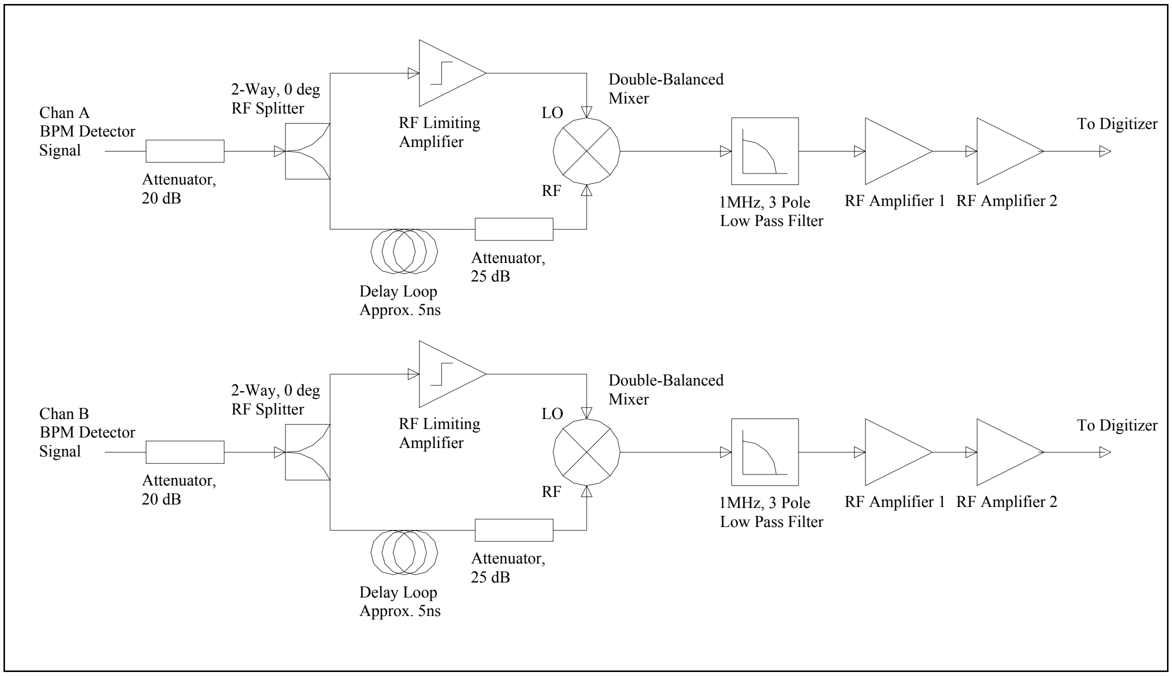

Figure 3.1 Synchronous Demodulator Block Diagram.

The mathematical explanation of the synchronous demodulation is as follows. Both dominant frequencies in the BPM signal are considered. Start with BPM signal $U_1(t)$.

$$U_1(t) = A(t) \cdot Cos(\omega_1 \cdot t) + B(t) \cdot Cos(\omega_2 \cdot t)$$

The signal is split. One copy is amplitude limited by the RF Limiting Amplifier. The phase of the other is adjusted to compensate for the phase delay through the RF Limiter, so that the two signals are in phase with one another at the input to the mixer. Let the limited LO signal be $U_2(t)$. Let the RF signal be $U_3(t)$.

$$U_2(t) = L \cdot [Cos(\omega_1 \cdot t) + Cos(\omega_2 \cdot t)]$$

$$U_3(t) = \tfrac{1}{2} \cdot A(t) \cdot Cos(\omega_1 \cdot t) + \tfrac{1}{2} \cdot B(t) \cdot Cos(\omega_2 \cdot t)$$

The expression describing the multiplication of the signals by the mixer is

$$\begin{aligned} U_2(t) \cdot U_3(t) = {} & \tfrac{1}{2} \cdot L \cdot A(t) \cdot [Cos(\omega_1 \cdot t) \cdot Cos(\omega_1 \cdot t) + Cos(\omega_1 \cdot t) \cdot Cos(\omega_2 \cdot t)] \\ & + \tfrac{1}{2} \cdot L \cdot B(t) \cdot [Cos(\omega_1 \cdot t) \cdot Cos(\omega_2 \cdot t) + Cos(\omega_2 \cdot t) \cdot Cos(\omega_2 \cdot t)] \quad . \end{aligned}$$

We can apply the following trigonometric identity to the expression for the mixer output.

$$Cos(x) \cdot Cos(y) = \tfrac{1}{2} \cdot Cos(x - y) + \tfrac{1}{2} \cdot Cos(x + y)$$

Then,

$$U_2(t)\cdot U_3(t)=\tfrac{1}{2}\cdot\tfrac{1}{2}\cdot L\cdot A(t)\cdot\left[1+Cos(2\cdot\omega_1\cdot t)+Cos((\omega_2+\omega_1)\cdot t)+Cos((\omega_2-\omega_1)\cdot t)\right]$$
$$+\tfrac{1}{2}\cdot\tfrac{1}{2}\cdot L\cdot B(t)\cdot\left[1+Cos(2\cdot\omega_2\cdot t)+Cos((\omega_2+\omega_1)\cdot t)+Cos((\omega_2-\omega_1)\cdot t)\right]\quad .$$

The mixer output contains the demodulated base band signal and content above 50 MHz. Following the 1 MHz Low Pass Filter only the base band signal, $U_{bb}(t)$ remains.

$$U_{bb}(t)=U_2(t)\cdot U_3(t)=\tfrac{1}{4}\cdot L\cdot\left[A(t)+B(t)\right]$$

A base band signal is produced for both channels A and B for the BPM. The signals are digitized using the high speed, 12-bit digitizer in the IRM internet rack monitor. Refer to the document on the IRM Local Application for further discussion on how the signals are processed to compute the beam position.

More details on the circuit characteristics are given in the following sections and a list of the more important component parameters is given in Table 3.1.

3.1 The RF Limiting Amplifier

The AD640 Limiting Amplifier provides a fixed amplitude signal for signal frequencies beyond 120 MHz. The dynamic range of input intensities for which the output amplitude is fixed is approximately 30 dB. Figure 3.1.1 shows how the limiter output drops off quicker with the presence of noise on the input. For the MiniBoone application the 30 dB of usable range is sufficient.

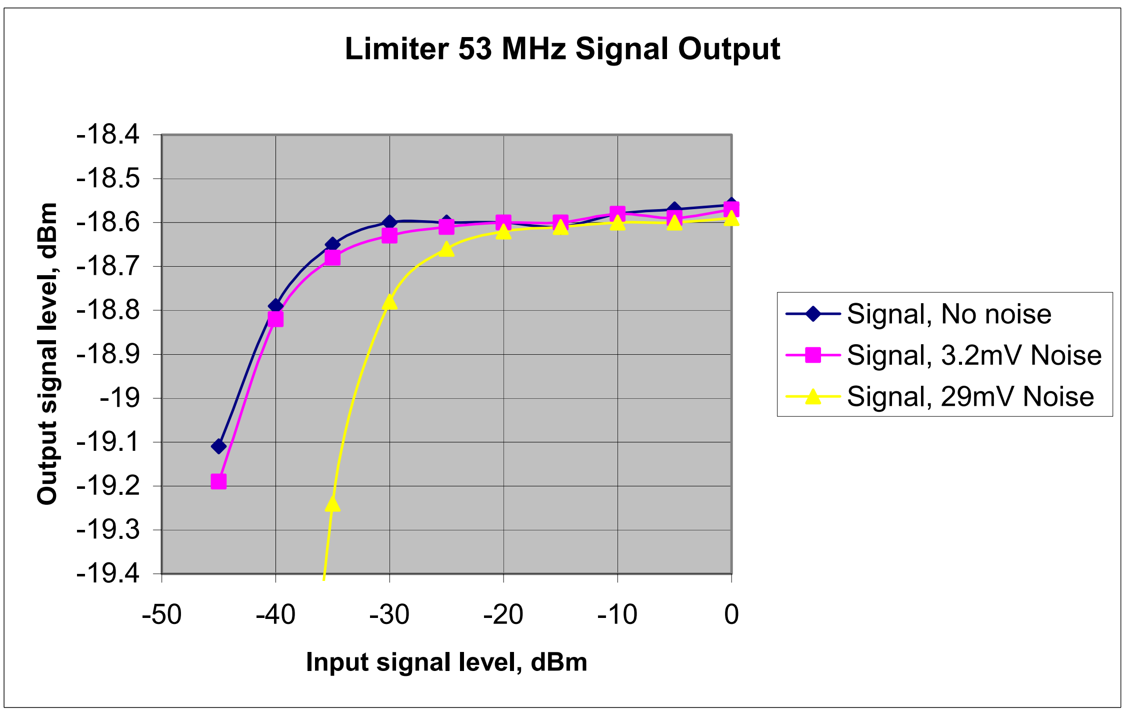

Figure 3.1.1 Limiter output amplitude versus input amplitude.

3.2 The RF Amplifier Offset and Gain Adjustment

The output offset of the synchronous demodulator is set to be 50 mV with no signal at the input. This is set with a simple turn pot connected to the common mode voltage input of the second AD8132 differential amplifier. This adjustment is subject to drift due to temperature changes. However the digitizer data processing always measures the initial baseline voltage just before the beam signal pulse and hence the absolute stability of the offset is not critical. The gain of the synchronous demodulator is set by three resistors of the final amplifier ; R29 + (R39 || R30) . These resistors are in a series / parallel configuration and allow for reasonable gain adjustment. In the end, calibration / correction coefficients are maintained for each synchronous demodulator which are applied during the final position calculation in the IRM.

Table 3.1 List of component parameters.

Item	Part Number	Manufacturer	Key Parameters
Attenuator, 20 dB	BW-S20W2	Mini-Circuits	Freq. Range: 1-18000 MHz Attenuation: 20 +/- 0.6 dB VSWR: 1.2 Power: 2 Watts
2-Way, 0 deg RF Splitter	JPS-2-1	Mini-Circuits	Freq. Range: 1-500 MHz Insertion Loss: 3.25 db Typ.
RF Limiting Amplifier	AD640	Analog Devices	3 dB Bandwidth: 145 MHz Limiter Gain: +50 dB Max Input (Pin 1, 20 to Com): -3 V to +300 mV Peak Diff. Output: +/- 180 mV
Delay Loop			Length: 13 inches Delay: approx. 5 ns
Attenuator, 25 dB	MAT-25	Mini-Circuits	Freq. Range: 1-1500 MHz Attenuation: 25 +/- 0.5 dB
Double-Balanced Gilbert Cell Mixer	AD608	Analog Devices	RF/LO Input BW: 500 MHz LO Input Power: -16 dBm 1 dB Compression: -15 dBm Max RF Input for linear Resp.: -22 dBm Mixer Gain: approx. 4 V/V
1 MHz, 3 Pole, Low Pass Filter Amplifier	AD8132	Analog Devices	High Speed Differential Amplifier 3 dB Bandwidth: 1.12 MHz Gain: 1 V/V Output Voltage Swing: +/- 3.6 V
RF Amplifier 1	AD8132	Analog Devices	High Speed Differential Amplifier 3 dB Bandwidth: 350 MHz Gain: 5 V/V Output Voltage Swing: +/- 3.6 V
RF Amplifier 2	AD8051	Analog Devices	High Speed Rail-to-Rail Amplifier 3 dB Bandwidth: greater than 5 MHz (110 MHz at G=+1) Gain: approx. 9 V/V

4. The Online Calibration Testing

Parameters for the IRM BPM On-Line Calibration

On-line calibration is accomplished by switching the electronic inputs to the BPM readout circuits from the BPM detector signals to a set of calibration signals. This is done using high frequency relays (SPDT) in each channel of the four BPM's the system supports. One digital output of the IRM is used to control each relay. A relay in the Calibration Module selects between two signal levels for the channel A test signal and another relay selects between two signal levels for the channel B test signal. This provides for three representative positions and two different intensities at the center position. A summary of the IRM digital outputs necessary are given in Table 4.1. A block diagram of the calibration circuit is shown in Figure 4.1.

Table 4.1 IRM digital outputs used to control the calibration testing.

Bit	Description
CAL[0:1]	Bits that control the representative position of the calibration test signal. (0,0) => Center position, higher intensity (1,1) => Center position, lower intensity (0,1) => Position Right (1,0) = > Position Left
BPMSEL_H1A	Signal Select for BPM H1 channel A
BPMSEL_H1B	Signal Select for BPM H1 channel B
BPMSEL_V1A	Signal Select for BPM V1 channel A
BPMSEL_V1B	Signal Select for BPM V1 channel B
BPMSEL_H2A	Signal Select for BPM H2 channel A
BPMSEL_H2B	Signal Select for BPM H2 channel B
BPMSEL_V2A	Signal Select for BPM V2 channel A
BPMSEL_V2B	Signal Select for BPM V2 channel B

Figure 4.1 Calibration circuit block diagram.